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Author(s):	Broussard, Leah J.
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Ultracold Neutrons at LANSCE

Leah Broussard

Los Alamos National Laboratory

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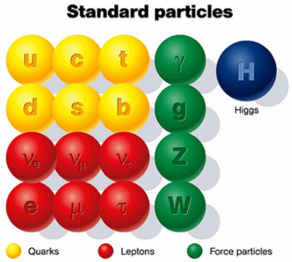
The Standard Model (and Beyond)



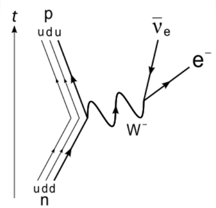
Some Curiosities

- Lots of "Why?'s"
  - Why 3 generations?
  - Why so many parameters?
  - Why these masses?
  - Why left-handed weak interaction?
- What is Dark Matter?
- Why so much matter?
- Where is gravity?
- And more...

Finding the missing pieces

- High Energy frontier (LHC) vs. Precision frontier (beta decay)
- Complementary approaches
  - High energy: Direct search for heavy particles
  - Precision: Measure deviations from SM expectation

Neutron Beta Decay



- Semileptonic charged weak interaction
- Standard Model: **V** - A (left-handed)
- Lifetime $\sim$ 15 minutes

What we can measure:

- Total decay rate (lifetime):
$$\frac{1}{\boldsymbol{\tau}_n} = W = K\,(G_F \mathbf{V_{ud}})^2 \left(1 + 3\left(\frac{\mathbf{G_A}}{\mathbf{G_V}}\right)^2\right)(1+\Delta_R)\, f_n p_e E_e (E_0 - E_e)^2 \left[1 + m_e \mathbf{b} \frac{f_b}{f_n}\right]$$
- Angular correlations:
$$\frac{dW}{dE_e d\Omega_e d\Omega_\nu} \propto$$
$$p_e E_e (E_0 - E_e)^2 \left[1 + \mathbf{a}\frac{\vec{p_e}\cdot\vec{p_\nu}}{E_e E_\nu} + \mathbf{b}\frac{m_e}{E_e} + \langle\vec{\sigma_n}\rangle \cdot \left(\mathbf{A}\frac{\vec{p_e}}{E_e} + \mathbf{B}\frac{\vec{p_\nu}}{E_\nu} + \mathbf{D}\frac{\vec{p_e}\times\vec{p_\nu}}{E_e E_\nu}\right)\right]$$

Testing the Standard Model

- **A**, **a** + $\boldsymbol{\tau}$ $\rightarrow$ **V**, **A** interactions ($\mathbf{V_{ud}}$, RL symmetry, ...)
- **B**, **b** $\rightarrow$ **S**, **T** interactions (BSM interactions, MSSM, ...)

Ultracold Neutrons

Class	Energy	Source
Fast	**> 1 MeV**	**Fission reactions / Spallation**
Slow	**eV – keV**	**Moderation**
Thermal	**0.025 ev**	**Thermal equilibrium**
Cold	**μeV – meV**	**Cold moderation**
Ultracold	**≤ 300 neV**	**Downscattering**

How cold is Ultracold?

- Temperature < 4 mK
- Velocity < 8 m/s
- Usain Bolt ~ 12 m/s

UCN can be bottled

- Gravitational ($V = mgh$): 100 neV / meter
- Magnetic ($V = -\vec{\mu} \cdot \vec{B}$): 60 neV / Tesla
- Material $\left(V = \frac{2\pi\hbar^2 Nb}{m}\right)$ $\begin{cases} {}^{58}\mathrm{Ni}: & 335 \text{ neV} \\ \mathrm{DLC}: & 250 \text{ neV} \\ \mathrm{BeO}: & 250 \text{ neV} \\ \mathrm{Cu}: & 170 \text{ neV} \end{cases}$

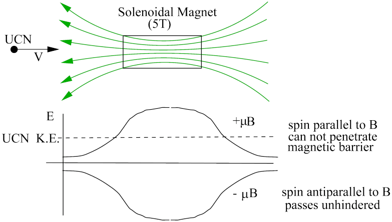
Manipulating UCN

Material bottles: UCN guides

- Features of good UCN guides:
  - Low "loss per bounce" ($< 10^{-5}$)
  - High Material Potential ($>$ 200 neV)
  - Low depolarization ($\sim 10^{-6}$)

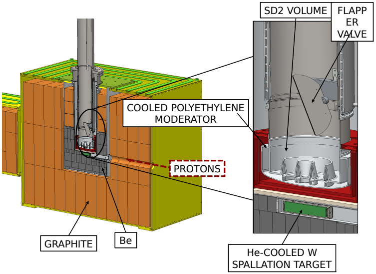
Magnetic selection: UCN polarizers

- Neutron magnetic moment μ due to spin
- 100% polarization possible

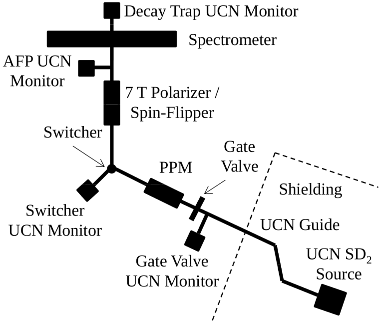


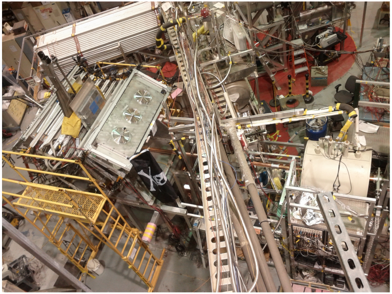
(note: neutron magnetic moment is negative)

Ultracold Neutron Facility at LANSCE

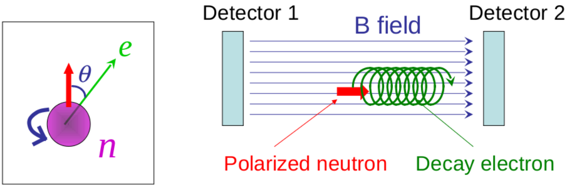


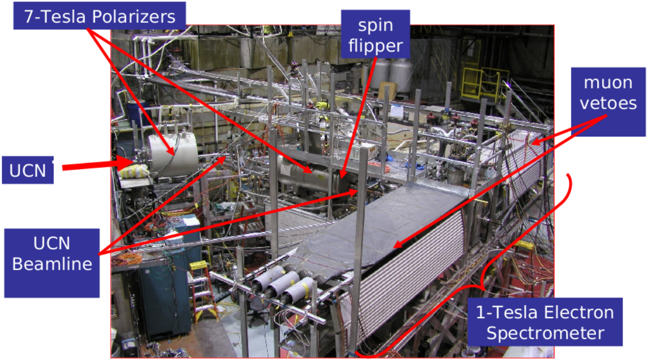
- 800 MeV proton beam + tungsten target $\longrightarrow$ spallation neutrons
- Single scatter in solid deuterium: CN$\rightarrow$UCN + phonon
- Remove phonons: SD_2 cooled to 4K
- "Flapper" shields UCN from SD_2
- 50 UCN/cc at shield wall
- Pulsed beam: Low background



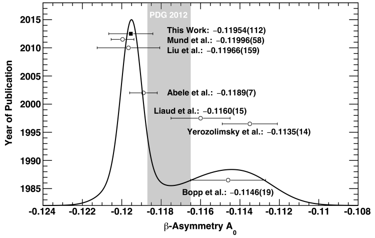


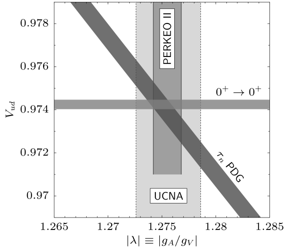
Experimental Programs at the UCN Facility: UCN**A**





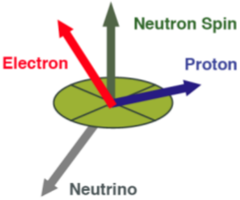
Experimental Programs at the UCN Facility: UCNA



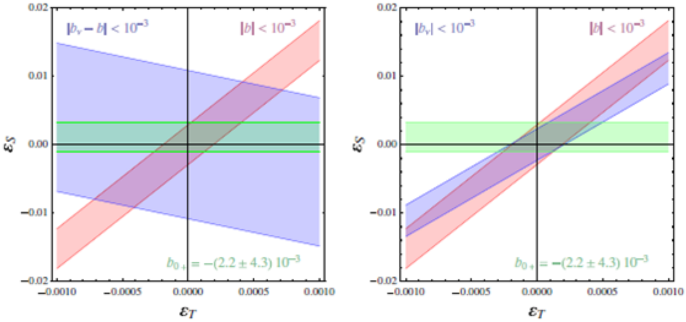


Corr. +/- Uncertainty (%)	Mendenhall (2013)	In analysis (TBS 8/14)	Next Step	Source of improvement
Statistics	+/- 0.46	+/- 0.40	+/- 0.28	Decay rate!
Depolarization	+0.67 +/- 0.56	+0.67 +/- 0.1	+0.6 +/- 0.1	Shutter+ ex situ
Backscatter	+1.36 +/- 0.34	+0.5 +/- 0.15	+0.5 +/- 0.15	Thin windows
Angle effect	-1.21 +/- 0.30	-0.8 +/- 0.2	-0.8 +/- 0.1	Windows+APD
Energy Reconstruction	+/- 0.31	+/- 0.08	+/- 0.08	Xenon + LED
Total Sys.	+/- 0.82	+/- 0.28	+/- 0.22	
Total	+/- 0.94	+/- 0.5	+/- 0.35	
	Dominated by systematics	Dominated by statistics	Intended to be balanced	

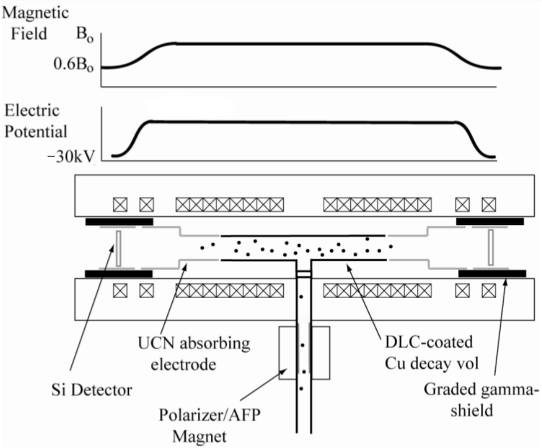
Experimental Programs at the UCN Facility: UCN**B**

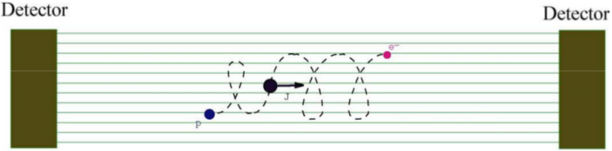


- 3-body decay: ν-asymmetry from proton/electron directions
- **B** is sensitive to **b**, $\mathbf{b}_\nu$ $\rightarrow$ non-Standard Model Scalar and Tensor interactions



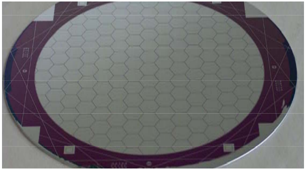
Experimental Programs at the UCN Facility: UCN**B**





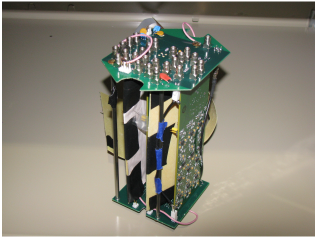
Experimental Programs at the UCN Facility: UCN**B**

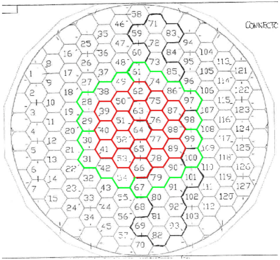
Novel thick, large area, highly segmented silicon detectors



Biased to -30 kV to accelerate protons

Custom preamplifiers: 24 ch instrumented





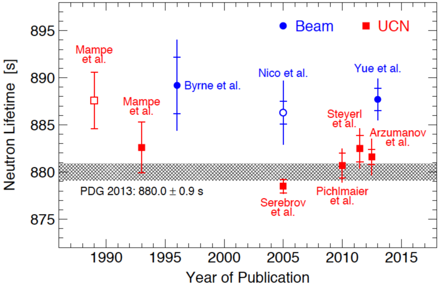
Experimental Programs at the UCN Facility: UCNτ

Neutron lifetime

- Precise tests of Standard Model
- Big bang nucleosynthesis
- Reactor and solar neutrino flux predictions

Beam vs. Bottle

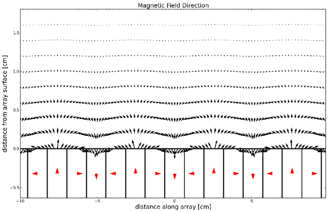
- Beam experiments: neutron flux?
- UCN bottle experiments: loss in the walls?

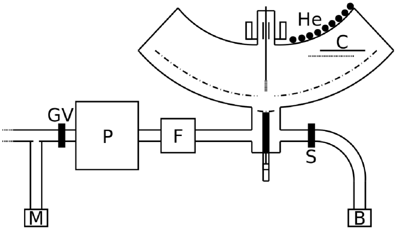


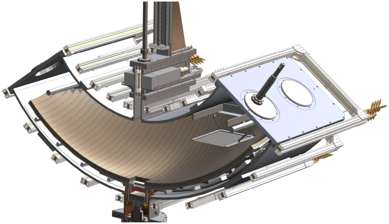
Experimental Programs at the UCN Facility: UCNτ

Magneto-gravitational Trap

- World's largest permanent magnet array
- Neutrons bounded by magnetic field on bottom, gravity on top
- No wall losses!

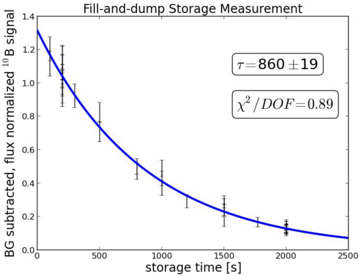






Experimental Programs at the UCN Facility: UCNτ

First storage time measurement (Feb 2013)



Current status

- Precision studies of systematics
- In-situ UCN counting
- Quasibound UCN cleaning?
- Monte Carlo UCN simulations
- Goal for prototype: 1 s precision measuremnt
- Ultimate experimental goal: 0.1 s precision